Spatial heterogeneity of soil nutrients in old growth forests of Korean pine[1]

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Abstract In this paper, we used geostatistics studied the spatial heterogeneity of total nitrogen and phosphorus on the top soil (0-10 cm) in old growth forests of Korean pine. There was a high degree of spatial heterogeneity of both nutrients which were dependent scales. The isotropic spatial dependent scale were 6.19 m (N%) and 11.10 m (P%). Both nutrients have anisotropic structures at sampled area. Spatial heterogeneity of autocorrelated was over 80%, and spatial autocorrelation was important in nutrient variations in space. This caused spatial patterns of total nitrogen and phosphorus in forest top soil.

Key words: Spatial heterogeneity, Semivariogram, Nitrogen, Phosphorus. *Pinus koraiensis*

Introduction

The importance of spatial heterogeneity comes from its central role in ecological theories and its practical role in ecology (Legendre *et al* 1989; Kolasa *et al* 1991; Dutilleul *et al* 1993). Li *et al* (1995) defines that heterogeneity is complexity and variability of a system property in space or time. A system property can be anything that is of ecological interest, e.g., population density, plant biomass, soil moisture or nutrients, vegetation type, and so on. Complexity refers to qualitative or categorical descriptors of the property, and variability refers to quantitative or numerical descriptors of the property (Li *et al* 1995). From this concept and operational definition we can understand how to quantitative and study the spatial heterogeneity which we are interest.

For the quantitative spatial heterogeneity, geostatistics is a powerful tool for assessing heterogeneity because the parameters from variogram model provide an index of both the magnitude and scale of spatial heterogeneity in a variate (Webster 1985; Trangmar *et al* 1985; Rossi *et al* 1992; Gross *et al* 1995; Li *et al* 1995). The parameters of sill, nugget variance, anisotropy, fractal dimension, and range in semivariogram can be used to be as descriptors for analysis spatial heterogeneity with scale (Li *et al* 1995; Wang *et al* 1997).

Soil properties contains systematic and random components an is spatial variations. Studies of soil variations by geostatistics are from about twenty years ago (Campbell 1978; Burgress 1980; Burrough 1983; Webster 1985). Nutrients in soil is an important property, nutrient availability is known to be highly heterogeneous in forests and is often associated with variation in forest species distributions and forest productivity. Between site, variation in forest species composition and structure has been associated with differences in rate of and variability in nutrient cycling, particularly in succession sere (Gross *et al* 1995). Even within a site, nutrient levels can very by up to an order of magnitude over relatively small spatial scales (Webster 1985; Robertson *et al* 1988; Gross et al 1995). Forest roots, e.g., fine roots, which main function is uptake nutrients and water from soil, are strongly effected by soil heterogeneity, especially by nutrient and water variations. Thus, from study spatial heterogeneity of soil nutrients and water, we can know the relationship between roots and nutrient or water variations.

We used a geostatistical analysis to quantify the magnitude and scale of spatial variability in soil nitrogen (N) and phosphorus (P) in old growth forest of Korean pine (*Pinus koraiensis* S.Z) in Northeastern China. Both nutrients are important issue in soil fertility, root growth and forest productivity. The objective of this study is to know the nutrients level and soil spatial properties due to know little about this whichever we have done many ecological researches above ground in this type old growth forests.

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Study site and data

The study site is the old growth forest of Korean pine, at the Liangshui Natural Reserve of Xaoxing'an Mountains, E 128° 48′ 30″ to E 128° 55′ 50″, N° 47′ 39″ to N 47° 14′ 22″, in Northeast parts of China. It is a typical forest vegetation and landscape in this region (Wang *et al* 1996; Li *et al* 1993).

The climate is terrestrial temperature and monsoon climate. Average annual temperature is -0.3 ℃. Temperature ranges from -43 ℃ to 38 ℃, and annual accumulated temperature($\geqslant$5 ℃) is about 2000 ℃. Annual precipitation is 676 mm. The frost free day is about 100 to 120 days. The total area of Lianshui Natural Reserve is about 6,394 hm^2, most stands are mixture between conifer (e.g., pine, spruce, and fir) and hardwoods (e.g., ash, birch, oak, aspen, maple, basswoods and walnuts). The stands age ranged from 200 to 300 a, and over 400 a from the dominate species of Korean pine. The typical soil under forests is dark-brown forest soil, which often distributed in mountain area or high sites, and in valley or lower sites is bog soil or peat soil, on plane site there is meadow soil.

The area site for this study was located inside of old growth forest stands of Korean pine. In the fall (Oct. 20) of 1995, we established a 40 m × 40 m grid at the site, slope was less than 6%. Most species are pine, spruce, mixed with birch, aspen and maple. Stand age was over 300 years old and never disturbed. We used random method to get total 118 soil samples, of which 73 samples from 0 to 10 cm layer, and 45 samples from 10 to 20 cm depths. The smallest sampling interval is 1 meters (Fig.1). At each sampling point we took a sample for measuring water content and other physical properties (e.g., pH, bulk density and so on), 400 g soil to polyethylene bag for nitrogen and phosphorus analysis in laboratory. We analyzed nitrogen(N%, NH_4^+, NO_3^-) and phosphorus (P%) for each soil samples.

Spatial variation of total nitrogen and phosphorus in study site were examined using geostatistical analyses (Webster 1995; Rossi *et al* 1992; Robertson *et al* 1997). Semivariograms for each variate were calculated using GS+, version 2.1 (Gamma Design Software 1992), using an unweighted least-square analysis for semivarigram model fitting. Model parameters, range, nugget, and sill, were used to estimate both the magnitude of spatial heterogeneity in a variate and the distance over which this spatial dependence is expressed (Li *et al* 1995; Gross *et al* 1995; Schlesinger et al 1996; Wang *et al* 1997). We calculated the proportion of the estimated total sample variation (sill or C+Co) explained by structural variance(C) for estimating the magnitude of spatial dependence (Li et al 1995). Where this proportion approaches 1, spatial dependence is very high, a large proportion of total sample variance is spatially dependent over the distance examined. Where this proportion approaches 0, apparent spatial dependence is low. The spatial scale of this dependence is indicated by the range (Ao), out of this range, the variety has a homogeneous. Nugget variance (Co) that dose not appear to be spatially dependent is either random error or represents spatial dependence at scales smaller than the minimum analyzed (Trangmar *et al* 1985; Issaks *et al* 1989; Rossi et al 1992). Anisotropy ratio and fractal dimension can be also determined spatial variation (Li *at al* 1995). Standardized semivariogram was used for comparing spatial heterogeneity of both nitrogen and phosphorus in soil. Variate maps were produced using ordinary block kriging (Journel *et al* 1978) with a block size of 0.2 m and the eight nearest neighbors across the field.

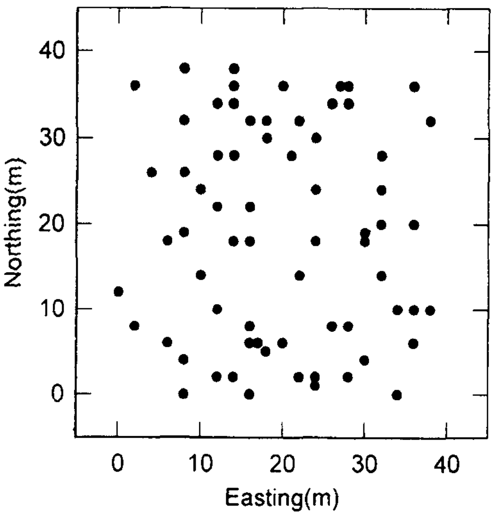

Fig.1. Diagram of plot locations and sampled for top nutrients in old growth forests of Korean pine

Results

The statistical parameters, before examining by semivariogram analysis, for nitrogen and phosphorus of Korean pine forest soil across the sampling area are given in Table 1. Variability of both nutrients are quite high, total nitrogen varied from 0.28% to 1.07%, and phosphorus varied from 0.15% to 0.38%. Coefficient of variation of nitrogen (29.31%) is higher than that of phosphorus (16.66). Both nutrients distributed as normality. Semivariogram parameters and fitting models are given in Table 2. For each nutrient, the isotropic semivariograms (Fig.3), standardized semivariograms (Fig.4), and anisotropic semivariograms (Table 3 and Fig.5) were constructed. Tow spatial pattern maps of total nitrogen and phosphorus were displayed in Fig. 6.

Table 1. Statistical parameters of total nitrogen and phosphorus in Korean pine forest soil (0-10 cm)

Nutrients	Units	Mean	SD	CV(%)	Max.	Min.	Sk	Ku	N
Nitrogen	%	0.58	0.17	29.31	1.07	0.28	0.709	3.424	73
Phosphorus	%	0.24	0.04	16.66	0.38	0.15	0.380	3.581	73

Table 2. Semivariogram parameters and fitting models for total nitrogen and phosphorus in Korean pine forest soil (0-10 cm)

Nutrients	Model	Co	Co+C	a	D	RSS	R^2
Nitrogen	spherical model	0.0060	0.0310	6.91	1.912	0.0008	0.332
Phosphorue	spherical model	0.0001	0.0018	11.10	1.945	0.0001	0.321

Table 3 Anisotropic semivariogram parameters and fitting models for total nitrogen and phosphorus in Korean pine forest soil (0-10cm)

Nutrients	Direction	Model	Co	Co+C	Co/Co+C	a	SSR	R^2
N(%)	0°	spherical model	0.001	0.031	0.032	3.50	0.0068	0.214
	45°	spherical model	0.001	0.033	0.030	13.20	0.0054	0.243
	90°	spherical model	0.004	0.037	0.108	18.90	0.0073	0.184
	135°	spherical model	0.002	0.035	0.057	14.20	0.0082	0.221
P(%)	0°	spherical model	0.0008	0.002	0.400	3.00	0.0004	0.186
	45°	spherical model	0.0007	0.002	0.388	12.50	0.0002	0.214
	90°	spherical model	0.0006	0.001	0.375	14.20	0.0001	0.316
	145°	spherical model	0.0007	0.002	0.388	13.40	0.0001	0.273

Discussion

Nutrient variations

Nitrogen and phosphorus are important nutrients for tree growth. Under undisturbed Korean pine forests, total nitrogen content is rich. Statistical results of 73 samples were shown in Table 1. There are about 0.58% nitrogen in 0 to 10 cm upper-layer, and 0.33% in 10 to 20 cm depth. In both layers, mean total nitrogen is 0.455%. Total phosphorus are 0.24% and 0.21% from 0 to 10cm and 10 to 20cm respectively. Long time nutrients were accumulated in top soil, and increased its higher content. But soil is a heterogeneity system. Nutrients have highly significant differences in upper-layers. Its coefficients of variation are 29.31% N and 16.66% P. The content range of total nitrogen and phosphorus in soil (0-10 cm) were 1.07%~0.28%, 0.38%~0.15% respectively, with a normal distribution (Fig. 2). There were high variations for both nutrients in sampled area.

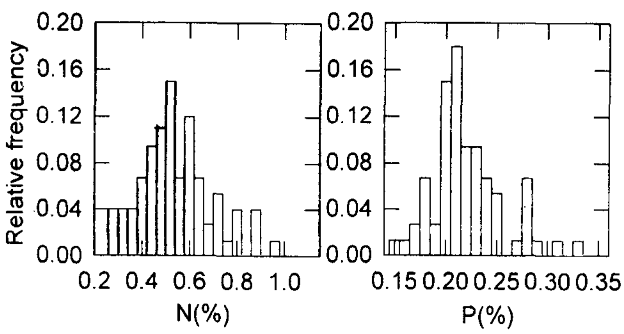

Fig. 2. Frequency distributions for total nitrogen and phosphorus on the top forest soil (0-10 cm)

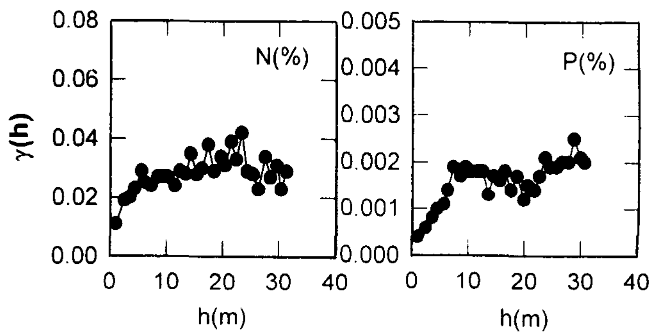

Fig. 3. The isotropic semivariograms of total nitrogen and phosphorus on the top forest soil (0-10 cm)

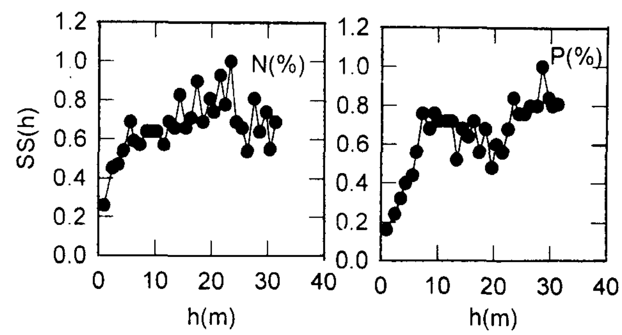

Fig. 4. Standardized semivariograms of total nitrogen and phosphorus on the top forest soil (0-10 cm)

Nutrient spatial isotropic variations

Isotropic semivariograms(Fig.3)for both total nitrogen and phosphorus showed increasingly strong autocorrelation at distances 6.91 m (for N%) and 11.10 m (for P%)(Table 2). Beyond that distance the isotropic semivariograms were essentially flat, indicating the region where classical assumptions of statistical independence may be justifies (Webster 1985; Journel *et al* 1989; Jackson *et al* 1993). This distance also means that isotropic scales of spatial variation of both nutrients in sampled area. The nugget variance, nonzero values but smaller, expresses the discontinuous variations at small scales. High sill means high degrees of spatial heterogeneity (Li *et al* 1995; Wang *et al* 1997). The nugget variance to sill ratio(Co/Co+C) show that the spatial heterogeneity of random were 19.35% and 5.55%, respectively, for total nitrogen and phosphorus. And the spatial heterogeneity of autocorrelated which was expressed by structure variance to sill ratio(C/Co+C) were 80.65% N and 94.45% P. The standardized semivariograms (Fig.4), using to compare different variables, display the same. Therefore, spatial heterogeneity of autocorrelated for both nutrients was important on the top forest soil (0-10 cm) at sampled area.

Nutrient spatial anisotropic variations

There were a stronger anisotropic structure and significant spatial heterogeneity, for both nutrients on the top soil (0-10 cm), among four directions (Fig. 5). At the direction 0°, variation scales were 3.50 m (N%) and 3.00 m (P%), direction 90°, it were 18.90 m (N%) and 14.20 m (P%), and about 12.50 or 14.20 meters in both 45° or 135° directionally. The nugget variance to sill ratio (in Table 3) shows that spatial heterogeneity of autocorrelated is dominant in anisotropic semivariograms for both soil nutrients. This is why we can found out that forest soil fertility was different from one place to another.

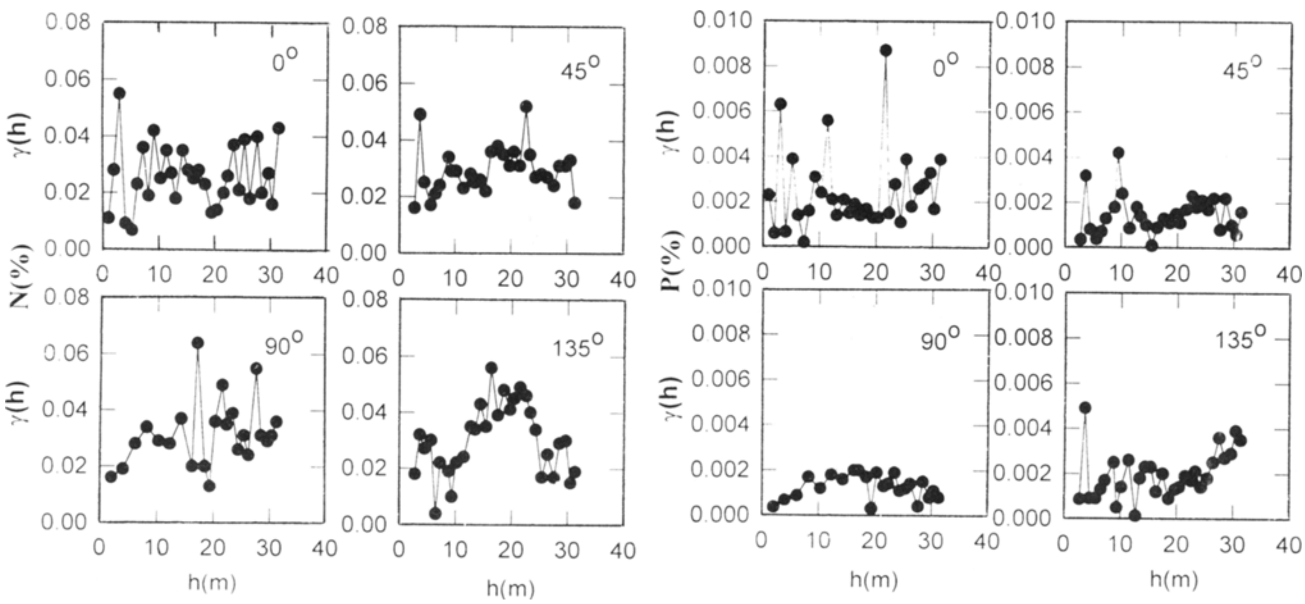

Fig. 5. Anisotropic semivariograms of total nitrogen and phosphorus on the top forest soil (0-10 cm)

Nutrient spatial pattern

Spatial heterogeneity determines the characteristics of spatial pattern in ecological system (Legendr *et al* 1989; Kolasa *et al* 1991, Li *et al* 1995). In the block kriging maps (Fig. 6), based on the anisotropic semivariogram models (Table 3), there were a high spatial heterogeneity of forest soil nutrients and spatial patterns of soil nitrogen and phosphorus on the top soil layer (0-10 cm) were significantly at the sampled area. The size of patches were a scale-dependent pattern due to spatial dependence of semivariogram is the function of scales, and patch distributions show that soil nutrients have the structural and random properties in space. This is because that the trees, shrubs and herbs which integrated nutrients cycling were spatial dependence and random (Wang *et al* 1996). Others, mosaics of microtopgraphy and soil moisture were also main factors which influenced soil nutrients. Patch shapes of fertility were anisotropy and its fractal dimension were 1.91(N%) and 1.95 (P%), respectively. The degrees of spatial heterogeneity of total nitrogen was higher than that of phosphorus by comparing both fractal dimension values (Table 2) and maps (Fig.6).

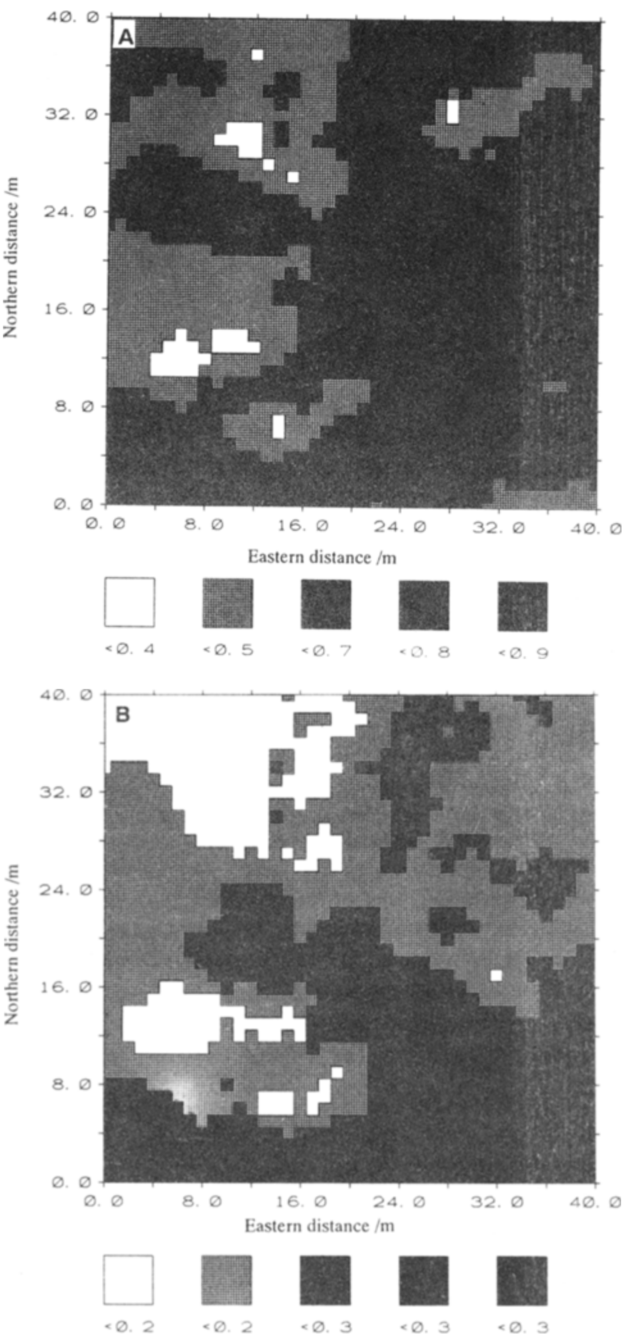

Fig. 6. Spatial pattern maps of total nitrogen(a) and phosphorus (b) on the and to forest soil (0-10 cm)

Conclusion

Forest soil is a high spatial heterogeneous systems. There were significant spatial variations of total nitrogen and phosphorus on the top layer (0-10 cm) in old growth forests of Korean pine. The spatial dependent scales were 6.19 m (N%) and 11.10 m (P%) in isotropic semivariogram models. Both nutrient variations in different directions at sampled area were anisotropic structures. Spatial heterogeneity of autocorrelated were dominant, therefore, its spatial pattern sizes were scale dependence in space. The patch distributions of nutrients have the structure and random properties which many environmental and biological factors influence its.

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